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BIOLOGICAL PARAMETERS AND PARASITE LOADS OF EEL POPULATIONS (*ANGUILLA ANGUILLA* L.) INHABITING TWO WATER BODIES IN COASTAL ALGERIA

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RESUME.— *Paramètres biologiques et charges parasitaires de populations d'Anguille (*Anguilla anguilla *L.) habitant deux systèmes aquatiques de la côte algérienne.—* L'évolution spatio-temporelle des paramètres biologiques (Lt, GSI, HSI, kc) des anguilles européennes, peuplant deux hydrosystèmes différents du littoral algérien, montre qu'il n'y a aucune différence significative de ces paramètres entre deux sous-populations d'anguille du lac Tonga, l'une parasitée (PT) et l'autre non parasitée (NPT) par le Nématode *Anguillicoloides crassus* ; mais nous notons une différence significative entre ces deux sous-populations d'anguilles du lac Tonga et la sous-population d'anguilles non parasitée (NPT) du port de Bou Haroun, sauf pour le poids total (W_t). Les valeurs les plus élevées du coefficient de condition (kc) sont observées chez les anguilles du lac Tonga. Le nombre élevé de parasites (NP $\geq$ 10) par vessie natatoire influence négativement tous les paramètres biologiques. Dans les deux stations, les conditions vitales des anguilles sont minimales en été et au printemps. L'analyse en composantes principales (PCA) distingue deux groupes d'anguilles. Le premier groupe réunit les individus du lac Tonga autour des indices parasitaires et de l'oxygène dissous. Le deuxième groupe réunit les anguilles du port de Bou Haroun autour des paramètres de pollution. Nous notons aussi que le parasite n'a pas été signalé au port de Bou Haroun du fait qu'il ne se développe probablement pas dans un tel milieu. Ce nématode ainsi que l'anguille préfèrent les milieux non pollués et à faible salinité, tel le lac Tonga.

SUMMARY.— Analysis of the spatiotemporal variation of the biological parameters of European eels (*Anguilla anguilla*) inhabiting two aquatic systems in coastal Algeria revealed no significant differences in length, gonadosomatic index, hepatosomatic index, or condition coefficient between non-parasitized (NPT) and parasitized (with the nematode *Anguillicoloides crassus*) (PT) sub-populations at Lake Tonga. However, there were significant differences in these parameters between the two Lake Tonga sub-populations and a non-parasitized population at Bou Haroun port (NPT). There were no significant differences in weight among these three sub-populations. The highest values of the condition coefficient were observed in eels at Lake Tonga. Parasite numbers $\geq$10 per swim bladder had a negative effect on all measured biological parameters. At both stations, the condition of the eels was lowest in the spring and summer. Principal components analysis distinguished two groups of eels. The first comprised the Lake Tonga individuals, separated by parasitic indices and dissolved oxygen. The second group comprised the Bou Haroun eels, separated by pollution parameters. In fact this parasite was not present at Bou Haroun, presumably because it is unable to develop in this environment. Both *Anguillicoloides crassus* and *Anguilla anguilla*, prefer non-polluted environments with low salinity, as found in Lake Tonga.

The European eel *Anguilla anguilla* Linnaeus, 1758 is a fish with a great economic and ecological importance. Since the 1980s, it has suffered a severe decline throughout its range, including in Algeria. The possible causes of this decline are multiple and include overfishing, obstacles to migration, anthropogenic pollution, and pathogenic agents, such as the endoparasitic nematode *Anguillicoloides crassus* (Kuwahara, Niimi & Itagaki, 1974) (Dracunculoidea: Anguillicolidae).

In the European eel, this hematophagous nematode inhabits the swim bladder, causing a condition called anguillicolosis. This endoparasite bores through the wall of the eel's stomach and enters the swim bladder, where it grows to the adult stage. The eggs are laid in the swim bladder, pass into the digestive tract, and the larvae are expelled in the faeces. Larvae are ingested by an intermediate host (shellfish or fish), where they develop into adults. Consumption of the intermediate host by an eel completes the cycle. The parasite causes a dysfunction of the swim bladder that interferes with migration of the eels towards their spawning area (the Sargasso Sea) (Brusle, 1990).

Originating from Japan, *Anguillicoloides crassus* was first reported in Europe in 1982, initially infesting Italian eels, and then moving to France (Dupont & Petter, 1988) and Germany (Koops & Hartmann, 1989). It has also been reported in North Africa, in Morocco (Hillali, 1996), Tunisia (Maamouri *et al.*, 1999) and Algeria (Meddour *et al*., 1999). There have been many studies of the eels in eastern Algeria, such as those in the wetland area of El Kala (Loucif *et al.*, 2009; Djebbari *et al.*, 2009). In contrast, the eels of central Algeria, such as those in the port of Bou Haroun, have been poorly studied.

In this study, we examined available data to determine whether the environmental conditions (salinity, dissolved oxygen, water potential, temperature, suspended matter, and turbidity) or the parasite (*Anguillicoloides crassus*) are primarily responsible for the decline in condition of Algerian eels. To this end, we investigated anguillicolosis of the Lake Tonga eels in relation to their size and weight, and to the season, and we examined the spatiotemporal variability of biological parameters in the populations of Lake Tonga and Bou Haroun port.

MATERIALS AND METHODS

STUDY SITES

Lake Tonga (36°53′N, 08°31′E) northeast of Algeria, is a freshwater lake extending over an area of 2500 ha, and is a protected area within the Mediterranean region. It is located in the Wilaya of El Tarf, 5 km east of El Kala and 6 km from Oum El Taboul (Algerian/Tunisian border). It is linked to the Mediterranean Sea through the Messida Channel (the obligatory passage of the eels to the sea).

Bou Haroun port (36°37′36″ N, 2°39′22″ E) is situated in Bou Ismail Bay on the coast 45 km west of Algiers and 25 km east of the Wilaya of Tipasa. The bay extends from Ras Acrata in the east to Mount Chenoua Cape in the west. It is regarded as the second most important fishing port in Algeria. However, its coastal fringe is subjected to domestic waste from the city and holiday resorts, which is discharged without treatment, except for wastewaters that are conveyed by wadis (Wadi Mazafran). The wadis cross the urban areas and flow into the sea, draining the runoff from farmlands and urban effluents (Fig. 1). The physicochemical parameters of the two stations are summarized in Table I.

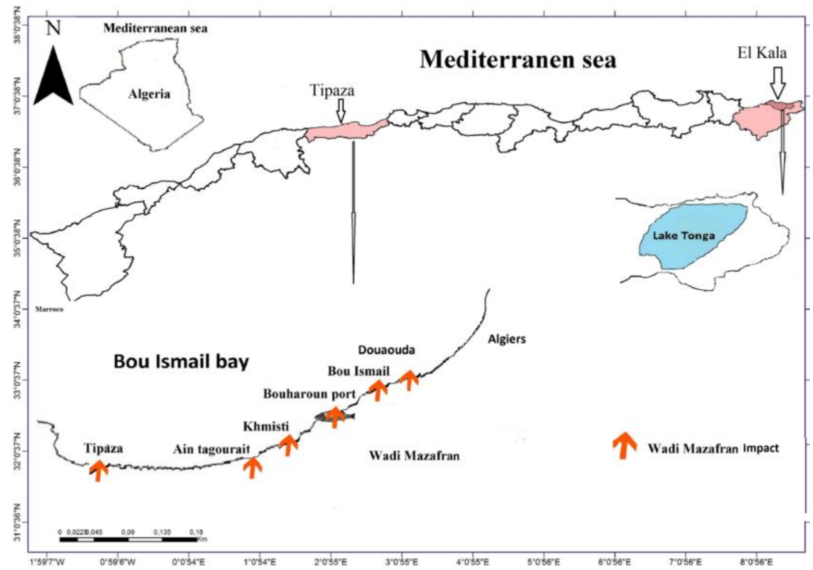

Figure 1.— Location of study sites.
Lake Tonga (El-Kala, W. Taref) and Bou Haroun port (Center - Algiers). ARC- GIS (2016).

TABLE I

Physico-chemical characteristics of the two stations, studied during the study period (Bou Haroun port - Lake Tonga)

Physico-chemical parameters	Lake Tonga	Bou Haroun port
Suspended matter (MES)	0.11mg/l	94.98 mg/l
Turbidity (Tur)	4.95NTU	98 NTU
PH	7.23	8.12
Temperature (T°)	12.96	18.07
Dissolved Oxygen (O_2)	24 mg/l	4 mg/l
Salinity (S%)	0.07 PSU	34.24 PSU

SAMPLING

Catches were carried out monthly at the two stations from January 2013 to January 2015. Eels were trapped by professional fishermen using funnel-shaped fixed bow nets. The bow nets consisted of 4 to 8 hoops and were provided with two vertical reflector nets, connected with the bank to drive the eels toward the opening, which was about 1 m in diameter. Nets (12-mm monofilament) were fixed to the bottom by stakes. We sampled 734 eels, 446 from Lake Tonga and 288 from Bou Haroun.

For statistical analysis, we separated the two geographic populations of eels into three sub-populations: Lake Tonga parasitized eels (PT), Lake Tonga non-parasitized eels (NPT), and Bou Haroun non-parasitized eels (NPB). No parasitized eels were present in those caught at Bou Haroun.

DATA COLLECTION

To assess the effects of location and anguillicolosis on the eels, the following parameters were recorded for each eel: total length (L_t, cm), total weight (W_t, g), eviscerated weight (P_{ev}, g), condition coefficient (kc), gonadosomatic index (GSI), and hepatosomatic index (HSI).

The condition coefficient is a measure of fish stoutness (Le Cren, 1951):

$$kc = 100^* W_{ev}/L_t$$

The gonadosomatic expresses the weight of the gonads relative to the eviscerated weight:

$$GSI = (W_g/W_{ev})^*100$$

If GSI is higher than 1% then the eel was designated as a silver eel, otherwise eel was recorded as yellow (Maamouri *et al*., 1999).

The hepatosomatic index expresses the liver weight relative to the total weight of the eviscerated fish:

$$HSI = (W_f/W_{ev}) \times 100$$

To characterize the level of infestation of Lake Tonga eels according to the season, and their weights and sizes, we computed three indices (Bush *et al*., 1997): prevalence (P = n/h), the ratio of the number of infested hosts (n) to the number of examined hosts (h); parasitic abundance (A = p/h), the ratio of the total number of parasites (p) to the total number of hosts (h); and parasitic intensity (I = p/n), the ratio of the total number of parasites in a sample of hosts (p) to the total number of infested hosts (n).

STATISTICAL ANALYSIS

Statistical analyses were carried out using the 'R' software package (R Development Core Team, 2014; http://www.R-project.org/). Data are presented as box and whisker plots and statistical differences among the three sub-populations were analysed using Kruskal–Wallis ANOVA, followed by Tukey's multiple comparison test. We also used below the 'Principal Components Analysis'.

RESULTS

SPATIAL EVOLUTION OF THE BIOLOGICAL PARAMETERS

Box-plots of the parameters recorded for the three eel sub-populations (Fig. 2) and the statistical analysis (ANOVA, Tukey; Tab. III), showed no significant differences ($p > 0.05$) in the mean values of Lt, GSI, HSI, or kc between the parasitized (PT) and non-parasitized (NPT) eel sub-populations of Lake Tonga. In contrast, there were significant differences (*t* test, $p < 0.001$) in these parameters between the Bou Haroun sub-population (NPB) and both sub-populations from Lake Tonga (PT and NPT). Differences in total weight (Wt) among the three sub-populations were not significant (*t* test $p = 0.058$) (Fig. 2, Tab. III).

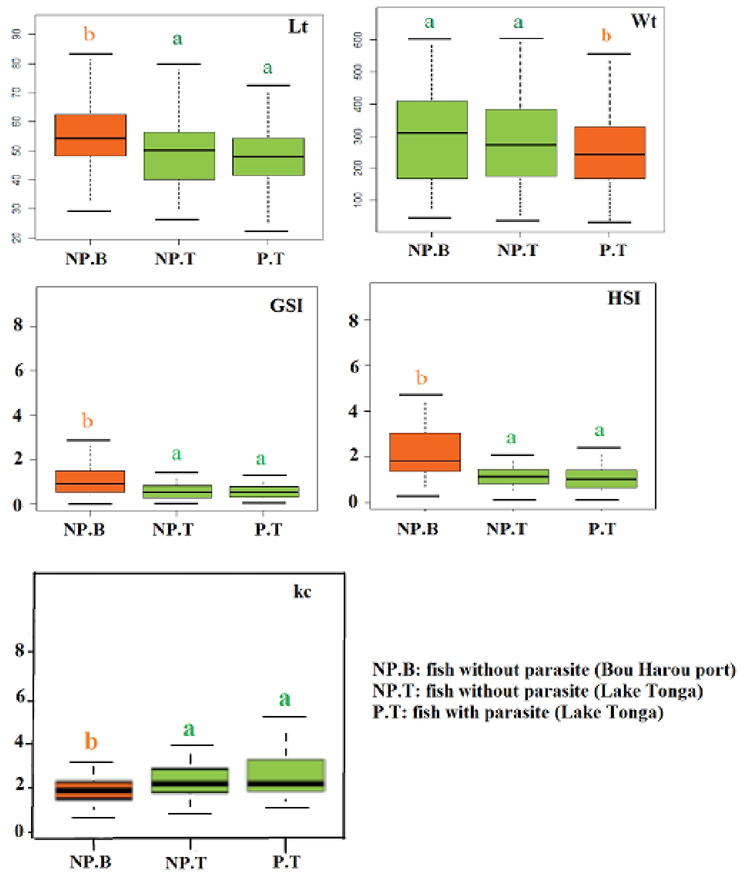

Figure 2.— Box plots of spatial variation of the biological parameters. Bou Haroun port (NPB); Lake Tonga, non-parasitized population (NPT) and parasitized (PT) (2013-2015). L_t: total length; W_t: total weight; GSI: gonadosomatic index; HSI: hepatosomatic index; kc: condition coefficient; **a** and **b,** represented by the ANOVA followed by Tukey's test)

TABLE II

Averages of the biological parameters of parasitized and non-parasitized fish at Bou Haroun port and Lake Tonga (2013–2015)

	L_t	W_t	GSI	HSI	NP	KC	AB	INT	PRV	**N**
N.P.B	53.89	243.37	1.001	2.02	0.18	0	-	-	-	288
N.P.T	50.10	286.45	0.58	1.11	0.21	0	-	-	-	240
P.T	45.69	262.44	0.53	0.97	0.21	5.7	2.64	3.77	2.39	206

L_t: total length; W_t: total weight; GSI: gonadosomatic index; HSI: hepatosomatic index; kc: condition coefficient; NP: number of parasites; AB: abundance of parasites; INT: parasitic intensity; PRV: parasitic prevalence, N: number of eels.

Therefore, except for differences in weight, the parasite did not appear to affect the condition of the eels in Algeria. The influence was rather a result of environmental parameters that break the parasitic cycle (intermediary host).

SPATIOTEMPORAL VARIATION IN BIOLOGICAL PARAMETERS

The spatiotemporal study revealed large ranges in the mean values of L_t (from 43.77 cm in PT in autumn to 60.52 cm in NPT in winter) and of Wt (from 169.25 g in PT in autumn to 370.05 g in NPT in winter) (Fig. 3a, b, Tab. IV), as well as of the reproductive indices (GSI and HSI)

(Fig. 3c, d, Tab. III). Conversely, the condition coefficient (kc) showed low variability (from 0.11 in NPB in spring to 0.3 in NPB in summer) (Fig. 3e, Tab. IV).

At Lake Tonga, the number of parasites was minimal in summer (4.67) and maximal (6.76) in autumn. No parasites were found in Bou Haroun port during the study period (Fig. 3f, Tab. IV). Spatiotemporal differences in the eel biological parameters (growth, reproduction, condition and parasitism) were statistically significant (Kruskal–Wallis, $p < 5$ %, Tab. III)

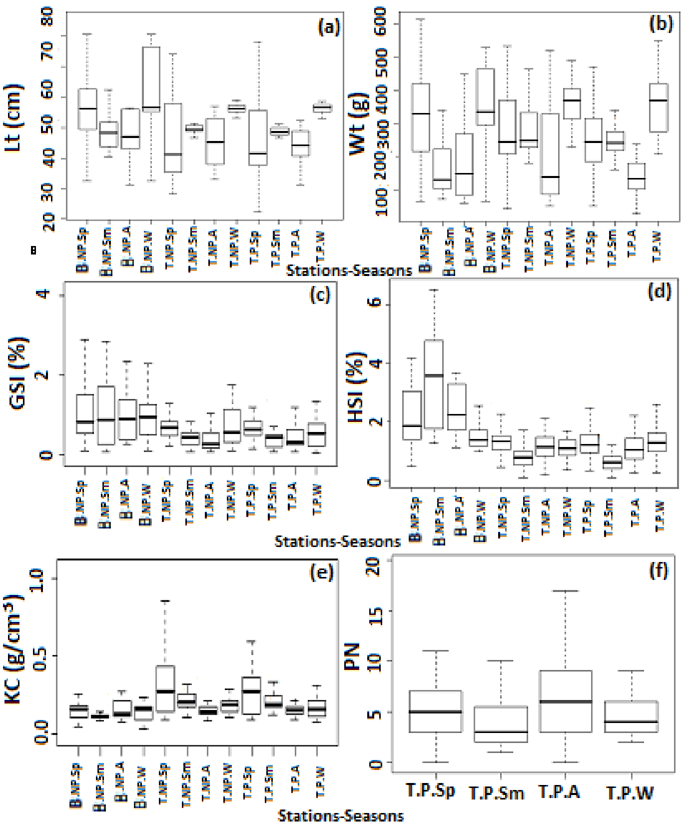

Figure 3.— Box plots of the seasonal variations of the biological parameters at the two stations, Bou Haroun port (NPB) and Lake Tonga (NPT and PT). B: Bou Haroun port, T: Lake Tonga, P: number of parasites, NP: none parasitized, Sm: Summer, Sp: Spring, W: Winter, A: Autumn.

WEIGHT AS A FUNCTION OF LENGTH

There were no significant differences in the weights of eels as a function of their lengths between the PT and NPT sub-populations at Lake Tonga. The most abundant size class was 40-60 cm. However, there was a significant difference in kc between the Bou Haroun (NPB) and the Lake Tonga sub-populations ($p < 2.2e-16$). There were more eels in the large size class (54-72 cm). Infestation by *Anguillicoloides crassus* had no effect on the growth in weight of the eels (Fig. 4).

RELATIONSHIP BETWEEN BIOLOGICAL PARAMETERS AND PARASITE LOAD

In the parasitized sub-population at Lake Tonga (PT), all of the measured biological parameters decreased with increasing parasite load, above 10 parasites per swim bladder of (Fig. 5a–c).

TABLE III

Spatial variation of biological parameters (Lt, Wt, GSI, HIS, kc) of three eel sub-populations (PT, PT and NPT)

Estimate (L_t)	Error		t value	pr> |t|		Significant
NPT -NPB	0	-6.677	1.404	-4.755	<1e-04***	Yes
PT - NPB	0	-8.178	1.292	-6.332	<1e-04***	Yes
PT - NP.T	**0**	**-1.501**	**1.247**	**-1.204**	**0.451**	**No**
Estimate (Wt)	Error		t value	pr> |t|		Significant
NPT -NPB	0	-18.90	16.94	-1.115	0.5043	No
PT - NPB	0	-36.97	15.59	-2.372	0.0473*	Yes
PT - NP.T	**0**	**-18.07**	**15.05**	**-1.201**	**0.452**	**No**
Estimate (GSI)	Error		t value	pr> |t|		Significant
NPT -NPB	0	-0.58069	0.09658	-6.013	<1e-06***	Yes
PT - NPB	0	-0.59966	0.08883	-6.751	<1e-06***	Yes
PT - NP.T	**0**	**-0.01897**	**0.08576**	**-0.221**	**0.973**	**No**
Estimate (HSI)	Error		t value	pr> |t|		Significant
NPT -NPB	0	-1.16930	0.10745	-10.882	<1e-05***	Yes
PT - NPB	0	-1.21839	0.09883	-12.328	<1e-05***	Yes
PT - NP.T	**0**	**-0.04909**	**0.09541**	**-0.515**	**0.864**	**No**
Estimate (kc)	Error		t value	pr> |t|		Significant
NPT -NPB	0	0.05727	0.02200	2.603	0.025642*	Yes
PT - NPB	0	0.07619	0.02023	3.766	0.000541***	Yes
PT - NP.T	**0**	**0.01892**	**0.01953**	**0.969**	**0.596**	**No**

Significant differences among means (ANOVA followed by Tukey's test) are indicated as follows: p<0.0001***, p<0.001; **, p<0.01; *; p<0.05.

TABLE IV

Spatiotemporal variations of biological parameters and parasitism index for eels at Bou Haroun port and Lake Tonga. NP: none parasitized; AB: parasite abundance; INT, parasitic intensity; PRV: parasitic prevalence.

Parameters	NP	AB	INT	PRV	T°	O2	PH	S‰$_0$	Ca	Cl	Tur	Na
BNP. Sp	0	2.57 ± 0.155	3.75 ± 0.222	0.99 ± 0.128	15.49	9.21	8.15	36.78	24.55	76.7	98	38.89
TNP. Sp	0	1.55 ± 0.209	1.88 ± 0.321	2.45 ± 0.223	18.06	18.15	7.01	0.5	2.4	22.4	4.95	22.2
TP. Sp	5,56 ± 0,388	1.65 ± 0.147	2.24 ± 0.268	2.54 ± 0.16	18.06	18.15	7.01	0.5	2.4	22.4	4.95	22.2
BNP. Sm	0	2.73 ± 0.257	3.18 ± 0.403	1.90 ± 0.282	15.49	9.21	8.15	36.78	24.55	76.7	98	38.89
T.NP. Sm	0	3.25 ± 0.018	3.78 ± 0.133	1.25 ± 0.18	18.06	18.15	7.01	0.5	2.4	22.4	4.95	22.2
TP. Sm	**4,67 ± 0,0605**	3.4 ± 00	4.86	2.7 ± 00	18.06	18.15	7.01	0.5	2.4	22.4	4.95	22.2
BNP. A	0	2.07 ± 0.029	2.70 ± 0.476	2.14 ± 0.332	15.49	9.21	8.15	36.78	24.55	76.7	98	38.89
TNP. A	0	2.19 ± 0.162	2.66 ± 0.252	2.24 ± 0.178	18.06	18.15	7.01	0.5	2.4	22.4	4.95	22.2
TP. A	**6,76 ± 0,68**	2.42 ± 0.177	3.07 ± 0.304	3.05 ± 0.06	18.06	18.15	7.01	0.5	2.4	22.4	4.95	22.2
BNP. W	0	2.22 ± 0.22	3.42 ± 0.319	1.02 ± 0.0183	15.49	9.21	8.15	36.78	24.55	76.7	98	38.89
TNP. W	0	3.05 ± 0.02	4.53 ± 0.125	0.7 ± 0.026	18.06	18.15	7.01	0.5	2.4	22.4	4.95	22.2
TP. W	5,811	3.11 ± 0.033	4.95 ± 0.011	1.28 ± 0.164	18.06	18.15	7.01	0.5	2.4	22.4	4.95	22.2

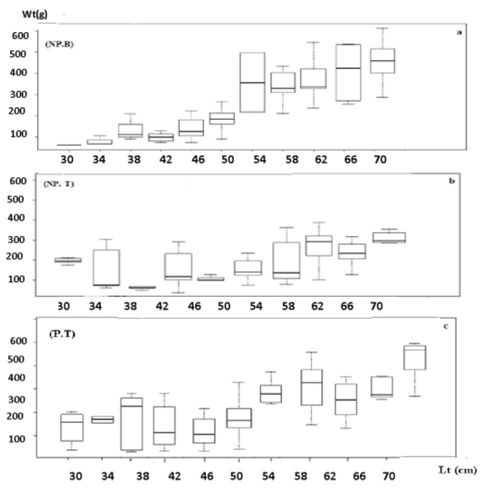

Figure 4. — Weight variations in terms of size-class for the three eel populations at the two stations. PT: Lake Tonga parasitized, NPT: Lake Tonga none parasitized, NPB: Bou Haroun ports none parasitized.

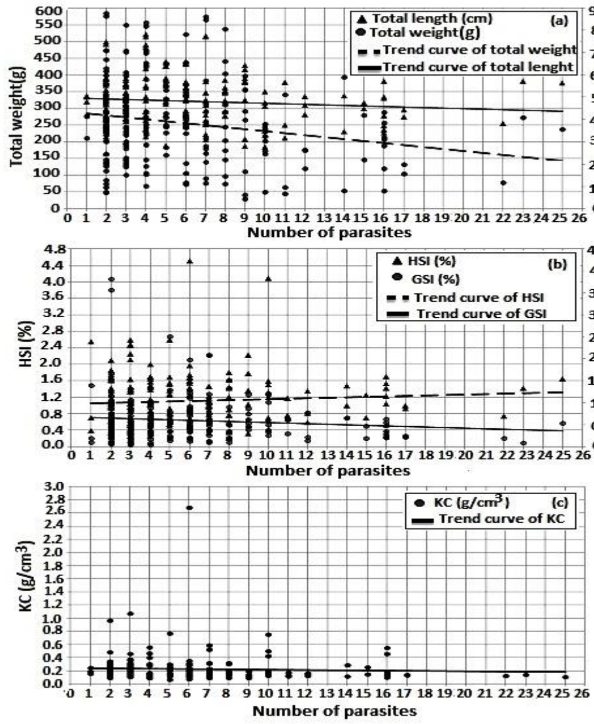

Figure 5.— Relationships between biological parameters and the number of parasites for Lake Tonga fish.

PRINCIPAL COMPONENTS ANALYSIS

Principal components analysis (PCA) was carried for 446 individuals registered on rows and 17 variables in columns, varying as a function of season and station. The eigen values are shown in Table V. The accumulated inertia was approximately 55 % but for the sake of clarity in the graphical representations, only the two first factorial axes were used (Dim 1, Dim 2).

TABLE V

Eigen values given by the R package version 3.0.2.

Observations	Dim 1	Dim 2
BNP. A	4.274	14.490
BNP. Sm	8.824	16.036
BNP. Sp	5.057	19.991
BNP. W	4.361	14.798
TNP. A	2.842	3.733
TNP. Sm	2.748	3.499
TNP. Sp	3.568	2.651
TNP. W	3.396	1.431
TP. A	3.898	8.039
TP. Sm	3.578	7.664

B: Bou Haroun port, T: Lake Tonga, P: parasitized, NP: none parasitized, Sm: Summer, Sp: Spring, W: Winter, A: Autumn]

PCA (Fig. 6) distinguished two large fish groups gathered around their characterizing variables. The first axis (Dim 1 = 57.79 %, Fig. 6A) showed positive correlations between the reproductive indices and the abiotic water parameters (turbidity, salinity, water potential and suspended matter) and negative correlations between the condition coefficient (kc), the number of parasites (NP) and the dissolved oxygen concentration (O_2). The second axis (Dim 2 = 21.91%,

Fig. 6) included the parameters Wt, Lt and the parasitic indices (prevalence, abundance and intensity).

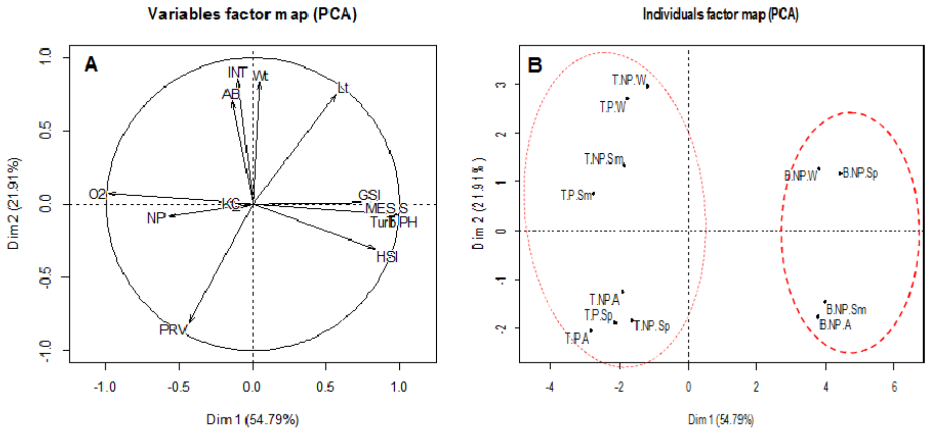

Figure 6.— Principal component analysis (total inertia: 76.7 %) of the biological and physicochemical parameters at Bou Haroun port and Lake Tonga. A: projection of parameters; B: projections of observations.

The projection of the observations allowed us to characterize the seasonal variability of growth, reproduction and parasitosis, as well as their spatial variability (Fig. 6B).

The eels, living in hyposaline waters (salinity 0.1 ‰, Lake Tonga), were highly parasitized with *Anguillicoloides crassus*, with prevalences higher than 64.5 %. In contrast, eels living in estuarine conditions (Bou Haroun port) were not parasitized. This may be because pollution by agricultural and industrial discharges and intense anthropogenic activity have eliminated the intermediate host (shellfish and fish), preventing completion of the parasitic cycle. The salinity (38 ‰) of the bays and estuaries seems to protect against parasitization of eels in Algeria without affecting the vital conditions required for growth, reproduction and feeding.

DISCUSSION

In Lake Tonga, the infested eels were generally in good condition, and there was no significant difference in condition (kc) between the parasitized and non-parasitized sub-populations. A similar situation was reported in the lagoons of Ghar El Melh and Lake Ichkeul-oued Tinja in Tunisia (El-Habbechi *et al.*, 2012), and at the Oued Sebou in Morocco (El-Hilali, 2007). The condition coefficient seems not to vary as a function of the presence of the parasite, or the degree of infestation. These observations are consistent with those reported by Koops & Hartmann (1989) in Germany.

The rates of growth in weight and length were similar in the healthy and infested Algerian eel sub-populations, provided the number of parasites was less than 10. A similar situation was reported in Tunisia (El-Habbechi *et al.*, 2012) and in France (Lefebvre *et al*., 2013). Some authors have reported that strong parasitization of eels with *Anguillicoloides crassus* caused bleeding, resulting in anemia and other metabolic perturbations, which impacted their growth (Molnar *et al.*, 1993). In the lagoon of Ghar El Melh (North Tunisia), Dhaouadi *et al*., 2014 also considered that the infestation of the eel swim bladder provokes congestion, bleedings, fibrosis and cell alterations. Elzbieta *et al.* (2015) noted that infestation of the European eel by the parasite provoked a decrease in the immune response. In Morocco, Yahiaoui *et al.* (2004) and Wariaghli (2013) observed that the largest eels feed more actively and, as a consequence, they probably become more strongly infested.

High parasitic loads (>10 parasites) had no effect on the hepatosomatic and gonadosomatic indices of our eels, as also observed in Tunisia (El-Habbechi *et al*., 2012). Rather, during the study period, the vital parameters of the eels reflected the state of the medium (salinity, oxygenation, temperature, water potential, suspended matter, and turbidity), particularly in autumn and summer. Lefebvre *et al*. (2013) note that currently, management of water salinity remains one of the best options for the control of the eel infection.

Anguillicoloides crassus seems specific to the host *Anguilla anguilla*, because it has not been found in other hosts. The absence of the parasite in polluted waters interferes with the parasite's life cycle, preventing infection of the eels. This is also the case in non-polluted environments where salinity and temperature are very high, especially during eel migration.

CONCLUSION

The highlights of this study are the following:

Eels living in a low-salinity environment (0.1 ‰, Lake Tonga protected zone) are highly infested with the parasitic nematode *Anguillicoloides crassus* (prevalence = 64.5 %). In contrast, those living in estuarine conditions (Bou Haroun port) are not parasitized. We conclude that the high salinity (38 ‰) of the bays and estuaries protects the eels from this parasite.

The spatial variation of the biological parameters of the eels indicates that parasite loads lower than 10 per swim bladder do not affect the biological parameters of eels in Algeria.

The nematode *Anguillicoloides crassus* and the eel *Anguilla anguilla*, prefer non-polluted environments with low salinity (e.g., Lake Tonga).

Indices of biological parameters of the eels at the two stations are lowest in spring and summer.

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